versity chemists and University of Nebraska chemical engineers developed a new, lower cost, and safer catalytic method of making brassylic acid. This method offers new promise for commercializing nylon 13,13 and other products. Jet engine lubricants and some synthetic automobile lubricants use the coproduct, pelargonic acid.

These and other as-yet-unforseen applications for oils high in erucic acid hold great promise for the future use of crambe and industrial rapeseed. However, for a significant increase in their use to occur, that promise must be transformed into commercial reality. With persistence and dedication, opportunity exists for researchers and business specialists to expand commercial markets for industrial products that use erucic acid, and thereby reap many benefits for American agriculture and industry. ❑

Castor and Lesquerella: Sources of Hydroxy Fatty Acids

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by Lewrene K. Glaser, Agricultural Economist, ERS, USDA, Washington, DC; Joseph C. Roetheli, Industrial Oilseeds Program Manager, CSRS, USDA, Washington, DC; Anson E. Thompson, Research Geneticist, U.S. Water Conservation Laboratory, ARS, USDA, Phoenix, AZ; Raymond D. Brigham, Associate Professor, Texas A&M University Agricultural Research and Extension Center, Lubbock, TX; and Kenneth D. Carlson, Chemist, National Center for Agricultural Utilization Research, ARS, USDA, Peoria, IL

Recorded use of castor oil dates back at least 4,000 years to when the ancient Egyptians used it in their lamps. In modern times, manufacturers have developed many products, ranging from lipstick to jet-engine lubricants, using castor oil and its derivatives.

Among commercial vegetable and petroleum oils, castor oil has unusual characteristics. Its chemical structure and hydroxy fatty acid content make it valuable for industrial applications.

During the 1950's and 1960's, about 80,000 acres of castor were grown annually on the High Plains of Texas. But domestic production decreased, and was finally abandoned altogether in 1972 when castor oil buyers and the farmer cooperative involved in crushing castor seed were unable to agree on their annual contract because of low world prices for castor oil and high local farm prices for competing crops. Since then, the United States

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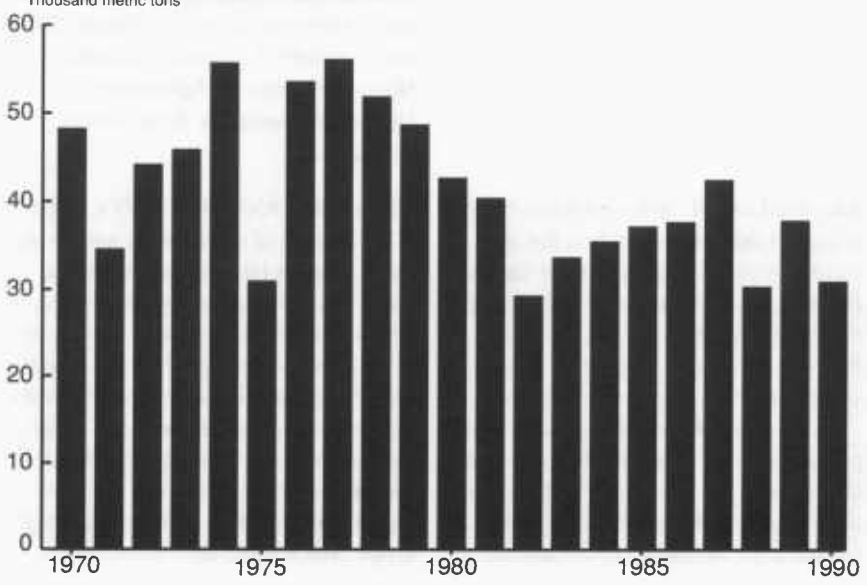
has imported an average of 41,200 metric tons of castor oil per year (see fig. 1).

Because of widely fluctuating world supplies and the structure of the world market, prices for castor oil vary considerably. These supply and price instabilities impose severe handicaps on users. They affect cash flow, make corporate planning difficult, and discourage investment in new products. Therefore, Union Camp Corporation and CasChem, Inc., the major U.S. buyers of castor oil, have worked with Browning Seed, Inc., scientists, and farmers to reestablish domestic castor production on the High Plains of Texas.

Figure 1

U.S. imports of castor oil, 1970-90



Robert Hawkins, consultant and former Union Camp Corporation purchasing agent, is familiar with fluctuating castor oil prices:

"Over the past 20 to 30 years, there usually has been a wild see-saw of world prices and production from one year to the next. World production declines when there is a drought in Brazil or India and prices rise 50 percent or more. Then in subsequent years, because of overplanting, prices drop sharply. They are now at a very low level, $650 per metric ton, compared to $950 per metric ton 3 years ago.

"By encouraging domestic production, we hope to dampen those cycles, so that customers will remain with castor-oil products rather than switch to alternatives when castor oil prices rise. If prices could remain relatively stable, perhaps somewhat higher than they are now, research and market development of castor products could be justified. But it is very hard for any company to support such efforts when you know prices will be very different 2 years down the line."

In contrast to castor, lesquerella has practically no history of cultivation and use. An experimental crop from the genus *Lesquerella,* it is being studied to provide U.S. manufacturers with a new domestic source of hydroxy fatty acids and U.S. farmers with a new source of income. Industry has noted the progress in crop production research and lesquerella oil's potential as a chemical raw material. As a result, several firms have joined USDA in its developmental efforts. Small acreages are being grown in several States as part of this project.

Hydroxy Fatty Acids

Why all this interest in castor and lesquerella? It is because the primary fatty acids in castor and lesquerella oils are unsaturated hydroxy fatty acids. Because of their special chemical attributes, hydroxy fatty acids are used in a wide range of products, including high-performance lubricants, cosmetics, waxes, nylons, plastics, and coatings.

Fatty acids are the building blocks of all vegetable oils. The chain length and chemical reactivity of a fatty acid help determine its value for industrial purposes. For example, the hydroxyl group (an oxygen and a hydrogen atom) gives castor and lesquerella a fatty acids special properties, such as higher viscosity and reactivity compared with other fatty acids. Furthermore, unsaturation (one or more double bonds within the carbon chain) provides additional sites for chemical reactions to occur. Castor and lesquerella oils offer two chain lengths and two types of unsaturation for novel reactivity and strategic applications. These attributes mean more opportunities to make different products and are a prime reason for industry's interest in hydroxy fatty acids.

Crop Characteristics

Native to Africa, castor (*Ricinus communis L.*) is grown throughout the world. In temperate climates, it is an

annual crop. Improved dwarf-internode varieties and hybrids developed in the United States range from 4 to 6 feet in height. Castor seeds, which contain over 50 percent oil on a dry-weight basis, are mottled brown and about the size of pinto beans. Almost 90 percent of the oil is ricinoleic acid[1]

Lesquerella is native to North America, ranging from Alaska to Alabama. The greatest concentration of species occurs in the southwestern United States and northern Mexico. Of the 23 lesquerella species scientists have studied, *Lesquerella fendleri*, a winter annual, has the best agronomic potential. Its tiny, dark-yellow seeds contain over 25 percent oil on a dry-weight basis, and about 55 percent of that is lesquerolic acid.[2]

Considerable genetic variation has been observed both within the genus and in *L. fendleri*, which appears to be highly cross-pollinated. These characteristics provide plant breeders with opportunities to improve the oil content of the seed and the amount of hydroxy fatty acids in the oil. There is also an opportunity to breed for desirable characteristics such as increased yield, erect growth, and other traits needed in a commercial oilseed crop.

Production practices for castor and lesquerella would be familiar to many farmers. Except for castor harvesting, both crops can be grown with only minor modifications to existing equipment. Special planting plates or air planters are used to handle fragile castor seeds. Planters and combines for lesquerella should be adjusted to handle its small seed. Cultural practices for castor are similar to those for cotton, corn, and sorghum, while lesquerella can be grown in a cropping system very similar to that used for winter wheat and other small grains in the Southwest. Overall, pesticide and fertilizer use may be lower than with traditional crops. Browning Seed, Inc., has developed an improved castor harvester-huller, which will lower harvesting costs and remove a major barrier to domestic production.

Processing

Four traditional methods exist to remove oil from oilseeds: expellers (screw presses), prepress-solvent extraction, full solvent extraction, and extrusion followed by full solvent extraction. Hexane is the usual solvent. Historically, crushers have used prepress-solvent extraction for castor seed. After expellers remove most of the oil, the remainder of the oil is extracted using solvents.

All four methods can be used to extract oil from castor or lesquerella seeds. However, pilot-scale experiments indicate that extrusion followed by full solvent extraction would be the optimum procedure for noncosmetic uses. The cosmetic industry prefers expeller oils because they have not come into contact with solvents like hexane.

Extruders pressurize the seeds into a pastelike mixture. Upon release, the material rapidly expands and dries. The resulting pellets, called collets, are very porous, which allows faster solvent penetration. Increasingly,

[1] 12-hydroxy-9-octadecenoic acid
[2] 14-hydroxy-11-icosenoic acid

commercial oilseed crushing plants are substituting extruders for expellers to prepare oilseeds for solvent extraction or to prepare nutritious high-energy meals for feeds.

In addition to the oil, meal is also a product of crushing oilseeds. Both lesquerella and castor meal have specific processing requirements, as do other oilseeds, because of certain components in the seed. Lesquerella seed contains glucosinolates. If the seed is not properly heat-treated, an enzyme is released during crushing that converts glucosinolates into antinutritional compounds that interfere with the animal's performance (feed consumption, weight gain, and feed efficiency). For cattle feed, the best way to maintain the quality of the meal is to inactivate the enzyme during processing, thereby preventing the breakdown of the glucosinolates. Research has demonstrated that this can be done in either cookers or extruders that prepare seed for oil extraction.

Castor seeds and meal contain a toxic protein, ricin, that can be fatal to humans if ingested, and a potent allergen, CB-1A, that can cause strong allergic reactions in sensitive people. Under a United Nations research grant, Texas A&M University perfected a system to deactivate the allergen as well as the toxin in the meal. A plant in Thailand is successfully using the process to treat 3 metric tons of castor meal per hour.

Products

Castor oil is used directly in many products such as transparent soaps, waxes and polishes, hydraulic fluids, inks, and metal drawing oils. However, most castor oil is further processed by the chemical industry. The resulting derivatives are used in a wide range of applications. For example, hydrogenated castor fatty acids are an ingredient in lubricating greases for cars, trucks, boats, railcars, aircraft, and industrial equipment. Nylon 11, based on derivatives of ricinoleic acid, is used in engineering plastics and powder coatings. Dehydrated castor oil and its fatty acids are components of coatings, inks, and sealants. Polyurethanes made from castor oil derivatives are used in electrical and telecommunication casting resins and coatings.

Chemists have conducted only minimal research on the uses of lesquerella oil. However, those tests, along with the known properties of fatty acids, indicate that it should be a good raw material for manufacturing industrial products. Ricinoleic acid (from castor) and lesquerolic acid have similar chemical structures. This means that both common and different products may be derived from the two hydroxy acids. Where higher molecular weights are important for the chemical properties of the products, lesquerolic acid could be superior.

Besides lesquerolic acid, *L. fendleri* oil contains oleic[3], linoleic[4], and linolenic[5] acids, common fatty acids used for animal feeds and industrial raw materials. Researchers, processors, and manufacturers are faced with the

[3] 9-octadecenoic acid

[4] 9, 12-octadecadienoic acid

[5] 9, 12, 15-octadecatrienoic acid

challenge of finding uses that utilize the entire oil or ways to economically separate lesquerolic acid from these other fatty acids.

Oilseed processor James Brown does not view castor and lesquerella as direct competitors. He envisions unique markets for lesquerella oil. Based on his 15 years of experience in developing markets for jojoba oil, Brown explains what is needed to launch lesquerella as an industrial crop.

"During the initial phases of new crop commercialization, the unit cost of lesquerella oil will be high relative to castor oil market prices. This is unacceptable to potential high-volume users such as lubricant, plastic, and ink manufacturers.

"A high-priced, low-volume market must be found to bridge the gap from the introduction of this crop to the ultimate cultivation of thousands of acres required to supply oil at commodity-chemical prices.

"In order to establish a commercial activity with lesquerella oil, we will focus on the high-value, low-volume market for cosmetic raw materials. We expect that cosmetic chemists and buyers will recognize and appreciate lesquerella oil's unique characteristics."

Treated castor meal and lesquerella meal could be used as protein supplements in livestock rations, primarily for beef cattle. During the 1960's and 1970's, when castor was grown and processed in Texas, detoxified castor meal was fed to cattle in the State. Initial feeding trials with lesquerella meal are currently under way, and preliminary results are encouraging. Meal entering interstate commerce would require approval by the Food and Drug Administration as a feed ingredient.

Future Prospects

The development of a domestic source of hydroxy fatty acids is dependent upon the advancement of castor and/or lesquerella production in the United States. Complementary opportunities exist to reestablish U.S. castor production and develop lesquerella as a new oilseed crop. Continued cooperation among industry, academia, and government—including public-private research programs and demonstration projects—is the most efficient and reliable way to make these opportunities a reality.

The immediate hurdle facing castor is the lack of a crushing facility. In 1991, plans to produce 10,000 metric tons of castor seed in the Texas High Plains stalled when negotiations for crushing the crop failed. Another problem is the perception of some processors in the area that buying food-grade corn from farmers growing castor means possible contamination of the corn with castor seed. Browning Seed, Inc., continues to search for a suitable facility, while farmers and castor-oil buyers stand ready to sign production and purchasing contracts.

Because lesquerella is an experimental crop, much work still needs to be done in its crop and product development. For example, additional

germplasm collection and plant breeding may increase seed yields, the percentage of oil in the seed, and the hydroxy fatty acid content of the oil. Further refinement of cultural practices, such as planting methods, weed control, and fertilizer and water use, is needed before lesquerella can be grown on a large scale. With expanded product research, lesquerella oil may create its own markets, distinct and separate from those for castor oil, because of its own special characteristics. ❑

The cosmetics industry would be a high-priced, low-volume market to introduce a commercially viable use for lesquerella oil.

Jack Dykinga/USDA 92BW0576-30

Anson Thompson, an ARS plant geneticist, examines lesquerella at the University of Arizona experimental farm near Phoenix. Because lesquerella is an experimental crop, much work still needs to be done in its development. Further refinements in planting methods, weed control, fertilizer use, and water use are needed before lesquerella can be grown on a large scale. *Jack Dykinga/USDA 92BW0576-14.*